Next Generation Gamma Diagnostics for the NIF (GCD/GEMS)

National ICF Diagnostics WGM

Hans W. Herrmann
Los Alamos National Laboratory

10/6/15

UNCLASSIFIED

NIF GCD Acknowledgements

H.W. Herrmann, Y.H. Kim, A. McEvoy, A. Zylstra, N. Hoffman, M. Schmitt, C.S. Young, V. Fatherley, F.E. Lopez, J. Griego, J.A. Oertel, T. Sedillo, T. Archuleta, R. Aragonez, S.H. Batha, R. Leeper

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AWE

M. Gatu Johnson, J. Frenje, R. Petrasso

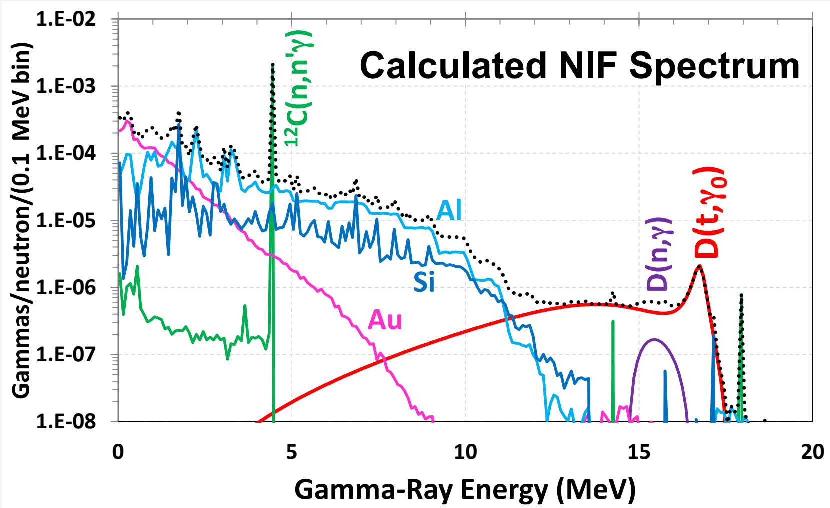
MIT

E.K. Miller, R. Malone

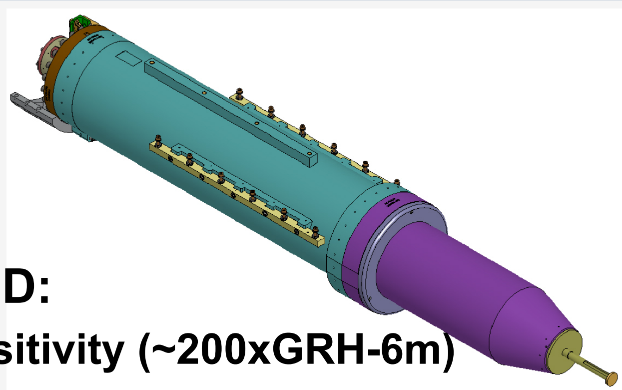
National Security Technologies LLC Vision • Service • Partnership

Next Generation Gamma Diagnostics will provide key burn parameters

Gamma spectrum is full of information

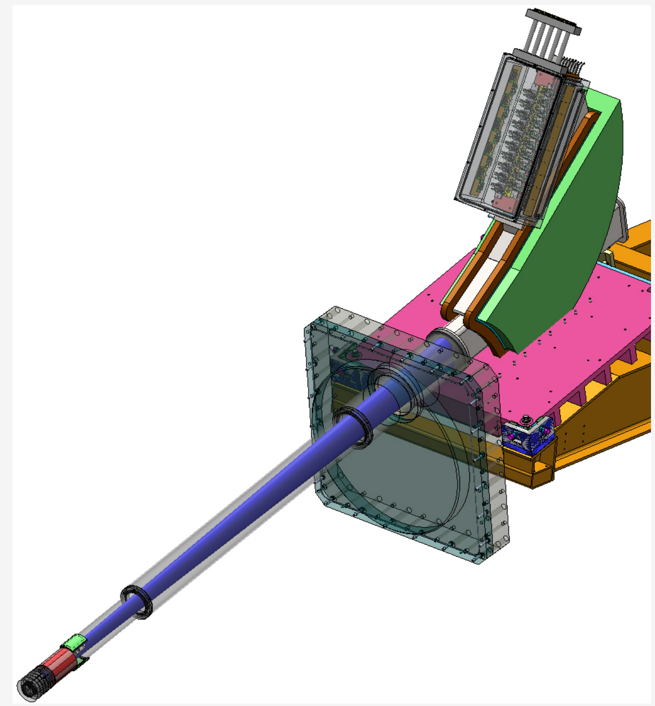


Enhanced Gas Cherenkov Detectors (GCD) for ρR_{Abl} and Reaction Histories



Super GCD:
- High Sensitivity (~200xGRH-6m)
- High Temporal Resolution (10 ps goal, ~10x faster than GRH-6m)

Compton Spectrometer for gamma spectral measurements

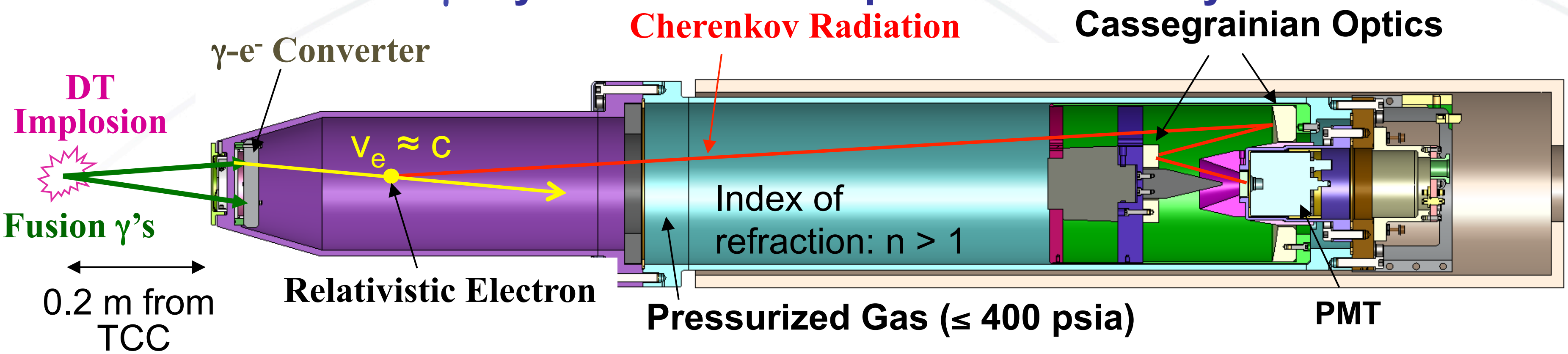


GEMS:
- Energy Resolution: $\Delta E/E \leq 5\%$
- Energy Range: $E_0 \pm 33\%$ within 2-25 MeV
- Temporal response < 1.5 ns
- Viable at $Y_{DTn} \geq 5e14$

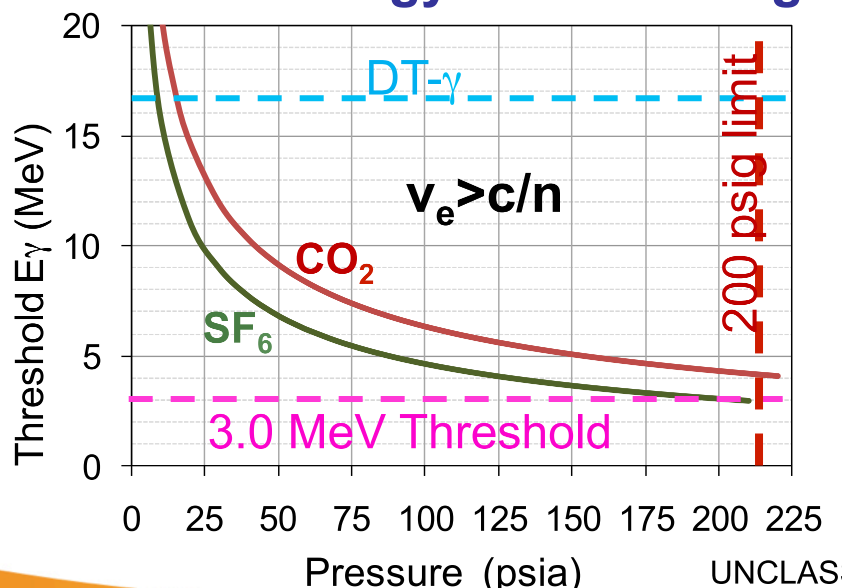
National Diagnostic Plan's "Transformative Diagnostics"
IFSA, G. Rochau We.S.4

Thresholded measurements are made with Gas Cherenkov Detectors (GCD)

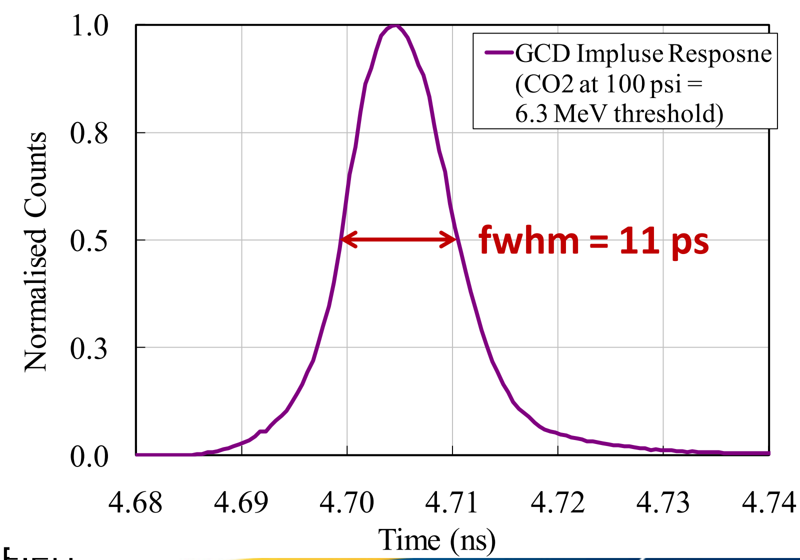
1. Converts MeV γ-rays to UV/Visible photons for easy detection



2. Variable Energy Thresholding

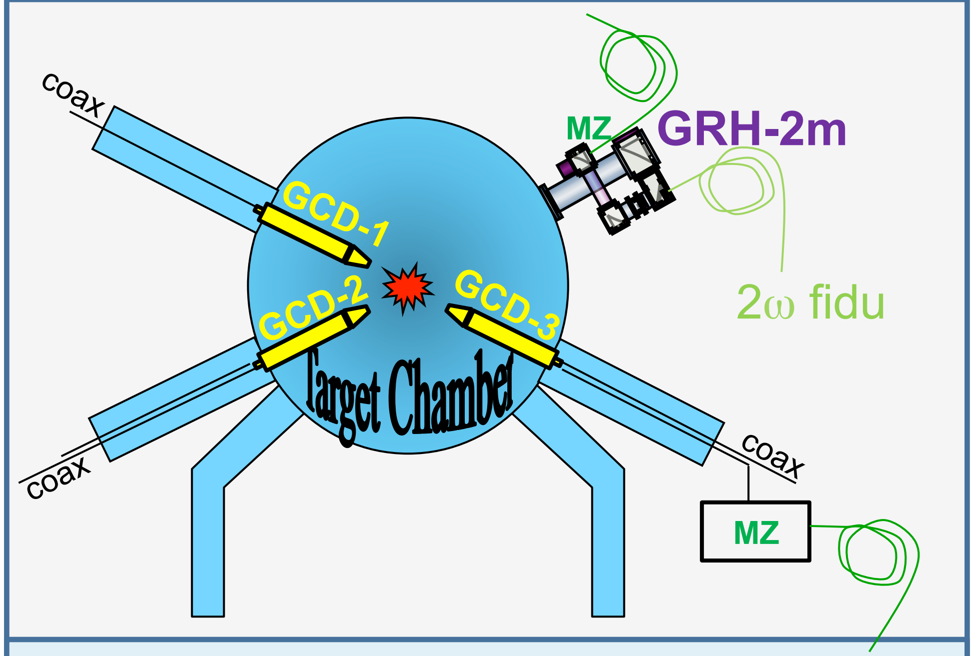


3. Fast Cherenkov Time Response



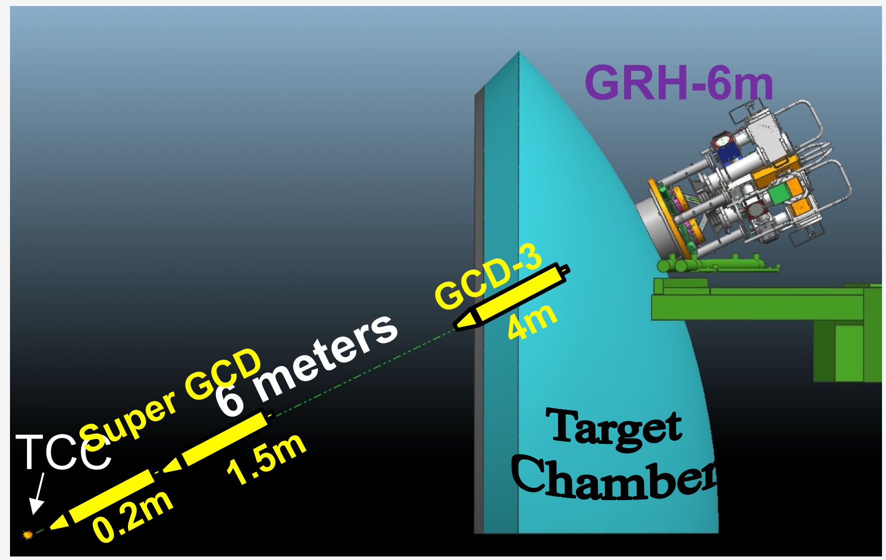
Gas Cherenkov Detectors have been in operations at OMEGA & NIF for many years

OMEGA-60



3 GCDs (20cm), 1 GRH (187cm)

NIF

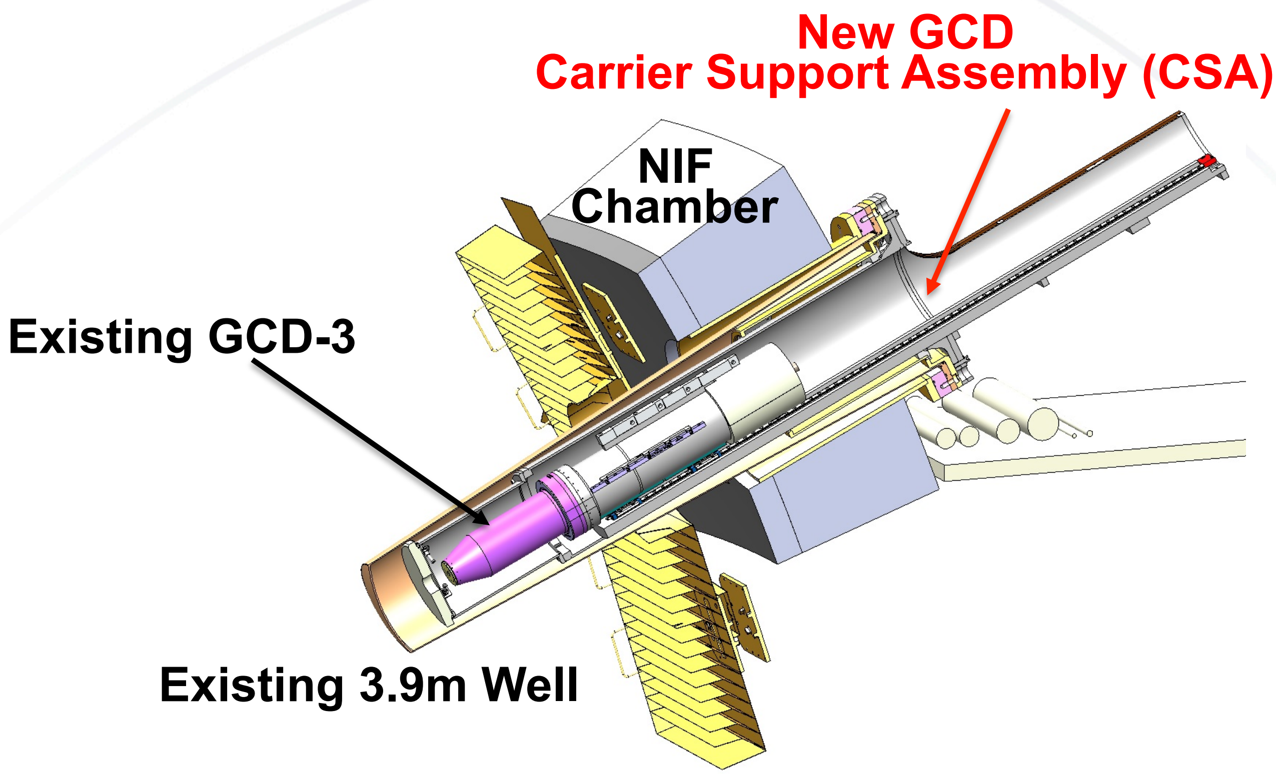


4 GRHs (607 cm)

Existing NIF GRH-6m has limited sensitivity due to large standoff distance

→ Bringing GCD to NIF

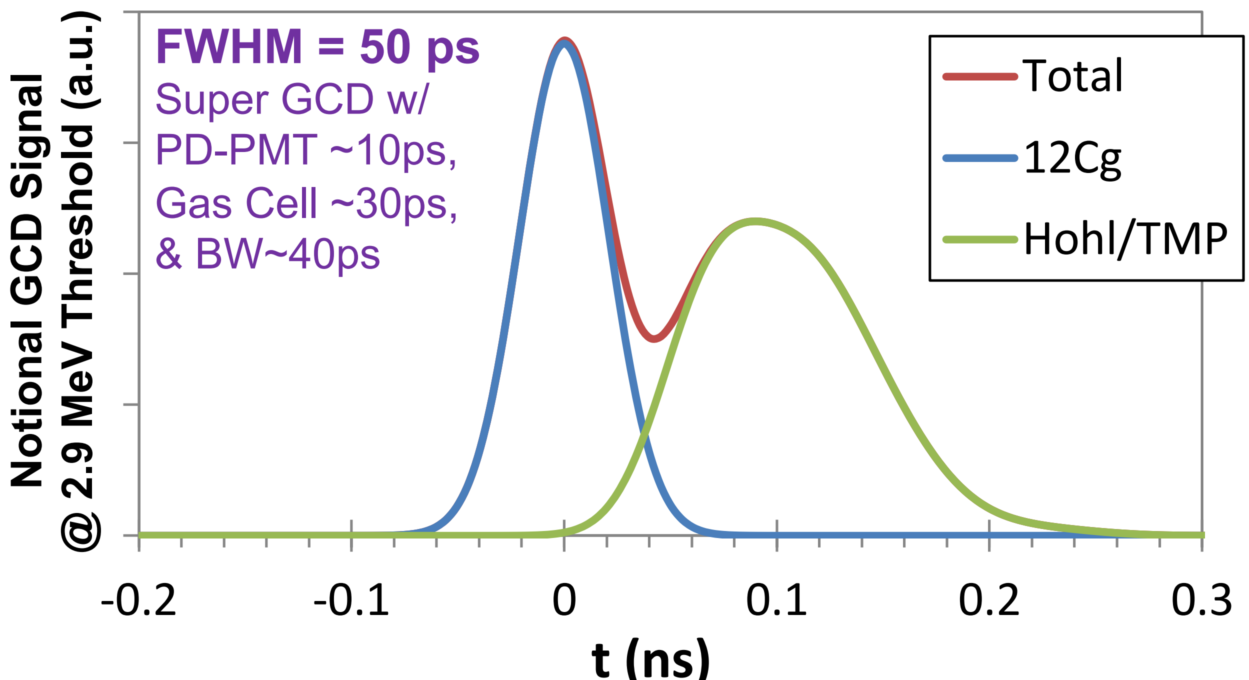
<u>Phase I</u> - GCD-3 in 3.9m Well with Photek Photodiode (~ 60 ps)



Physics: Improved temporal resolution for $^{12}C(n,n'\gamma)$

- Diagnosis of stagnation & mix for carbon-based ablators
- Background evaluation for Super GCD design
- Test bed for fast optical detectors

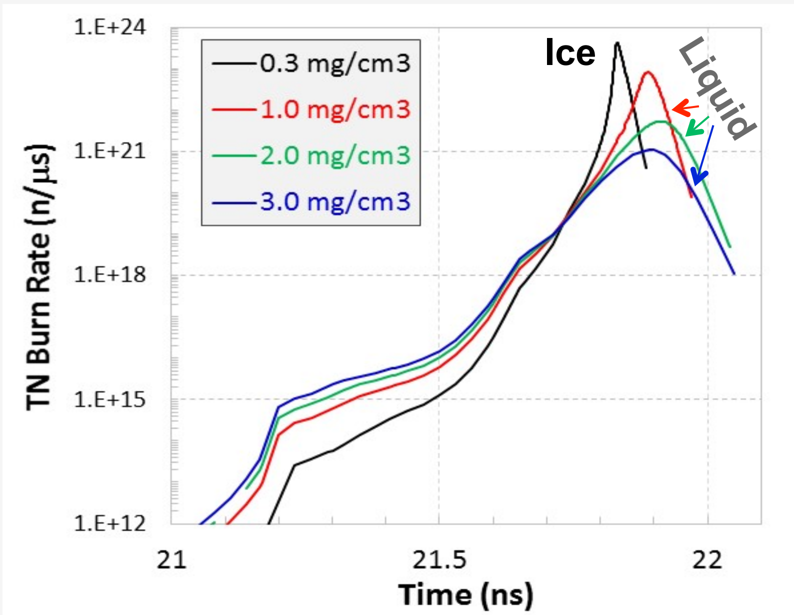
Goal: resolve $^{12}C\gamma$ and Hohl/TMP gammas to reduce uncertainty in carbon-based ablator ρR (CH & HDC)



- Convolution w/ Gaussian representing convolution of:
  - 1) Reaction History (currently ~125 ps)
  - 2) Gas Cell IRF (~40ps @ 2.9 MeV)
  - 3) Recording System IRF (currently ~100 ps)
- Current implosions total FWHM ~150 ps → ρR Uncertainty ~30%
- GCD-3 w/ PD designed for ~100 ps → ρR Uncertainty ~15%
- Super GCD w/ PD-PMT for ~50 ps → ρR Uncertainty <10%

Burn Widths are expected to narrow as implosion performance improves (i.e., approach 1D)

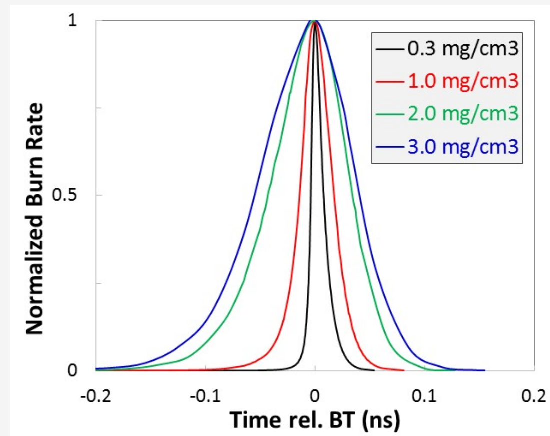
1D Ice vs. Liquid Layer Burn History

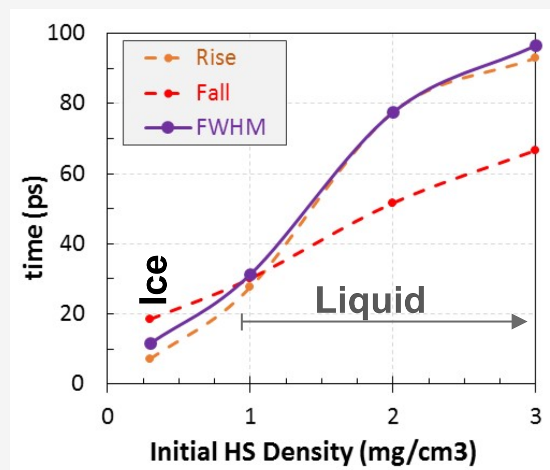


- Ice layers = high CR → diverge from 1D
- LANL Wetted Foam (WF) low-CR targets expected to approach 1D performance

R. Olson

Liquid BW < 100 ps expected

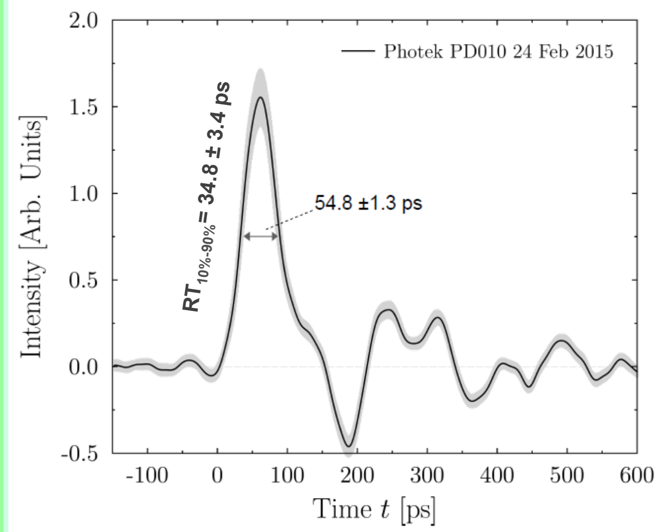




Implementing new High-Bandwidth, Low-Gain Signal recording

- Recording Bandwidth Goals: >10 GHZ (i.e., 35 ps Rise Time)
  - 8 GHz w/ 11x amplifier (for Y_{DTn}<1e16)
- Photodiode with unity gain
  - Simply a Photek PMT w/o the MCP (1 cm cathode)
  - New anode mask mitigates ring irreproducibility
- New Mach Zehnder network design
  - New low-V_{π} MZ by Covega
  - New dc-coupled PhotoReceivers to avoid previous GRH PR issues

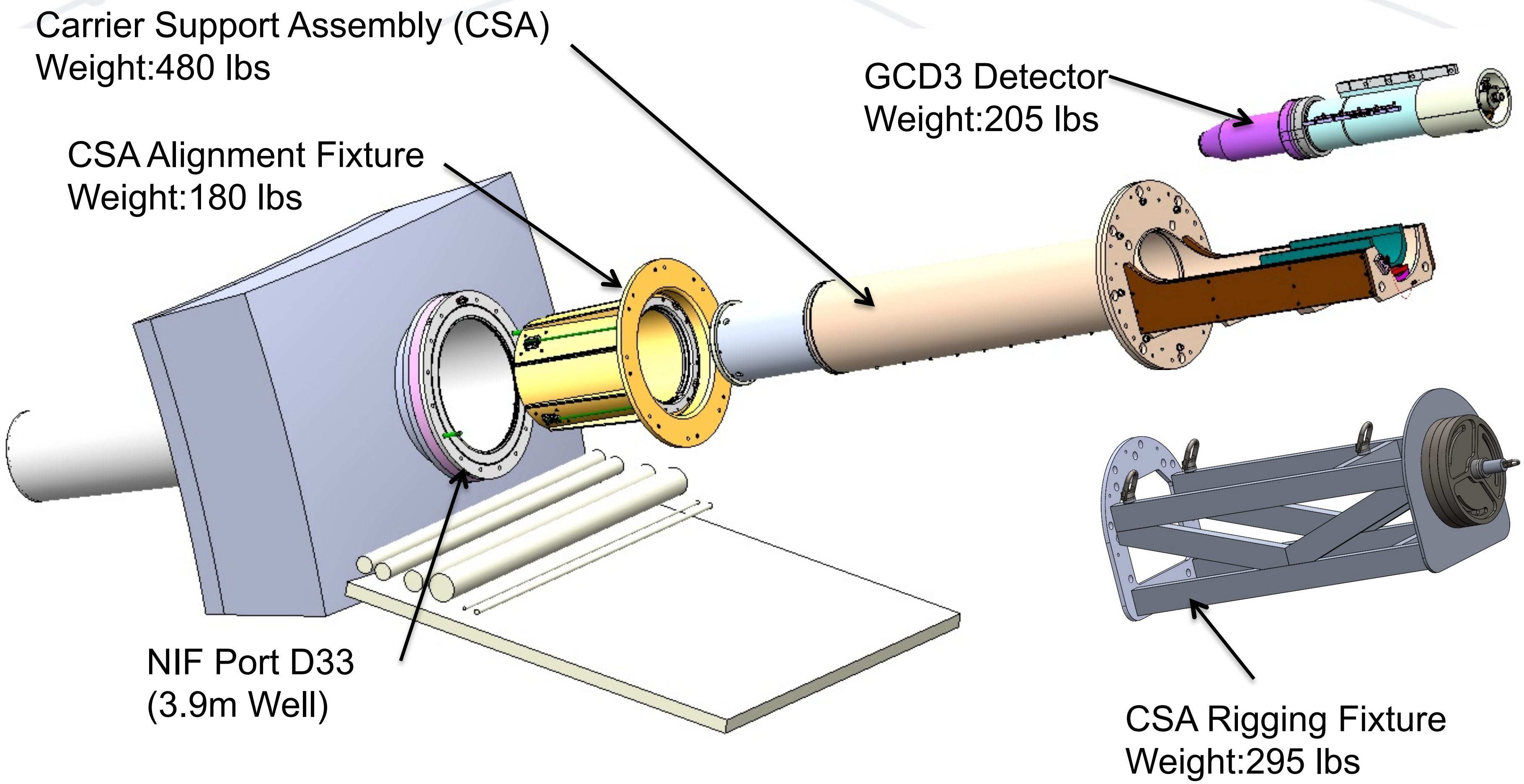
Photodiode IRF_{fwhm}= 55 ps



Average of 181 traces. Grey region is ± 1σ for the averaged dataset.

AWE

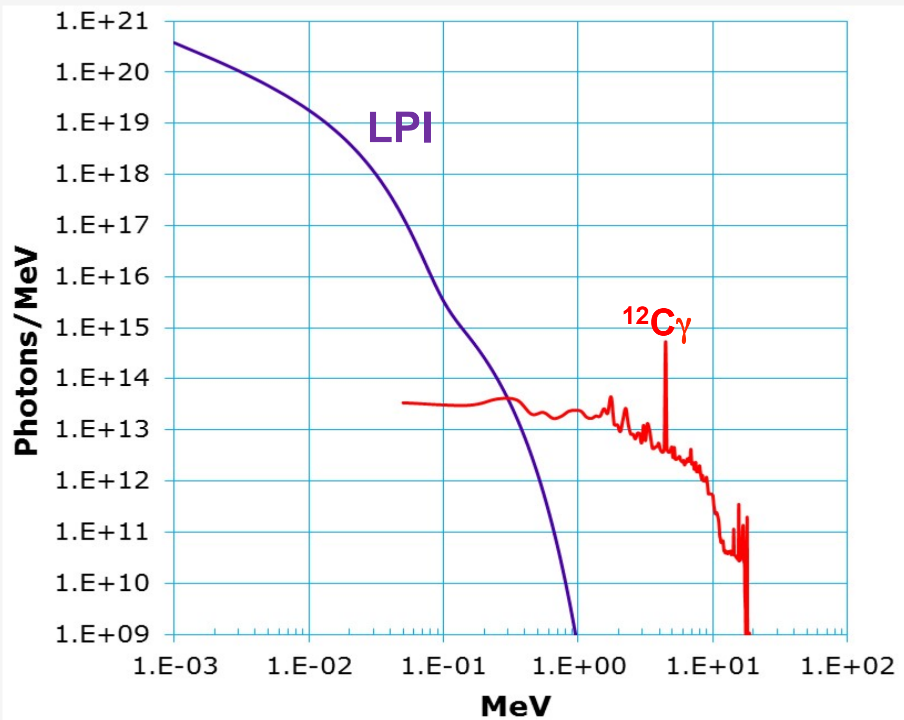
NIF-GCD3: Mechanical Systems Overview



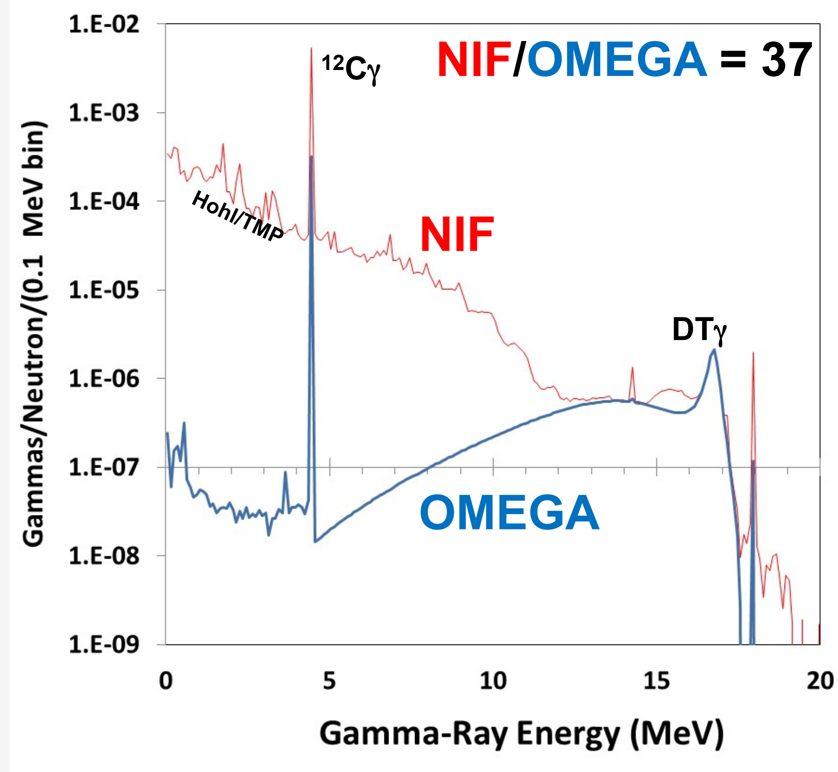
NIF FDR completed on 8/27/15, Operational by Spring 2016

Gamma detectors at NIF have to contend with backgrounds from:

LPI x-rays from gas-filled hohlraums



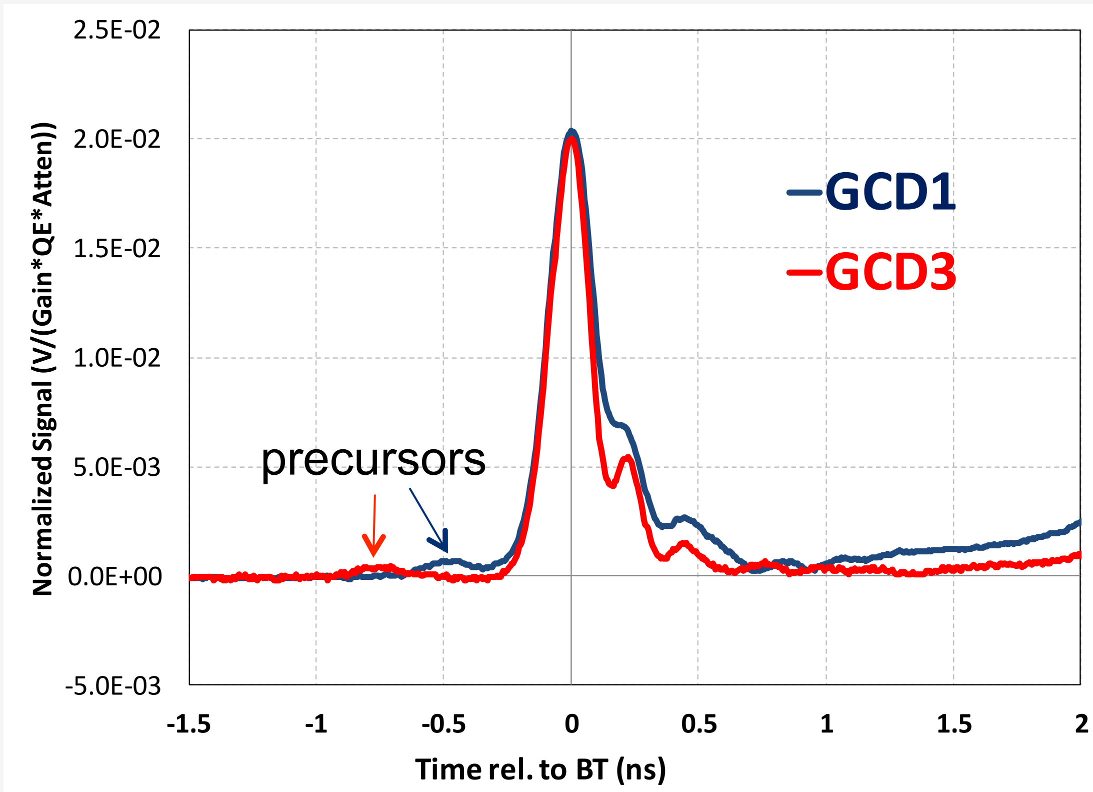
Prompt γ scattering background



ρR (mg/cm²)	OMEGA	NIF
^{12}C	30	500
DT	1	1500

OMEGA GCD-3 precursor used as basis for estimating LPI x-ray & Prompt Gamma backgrounds at NIF

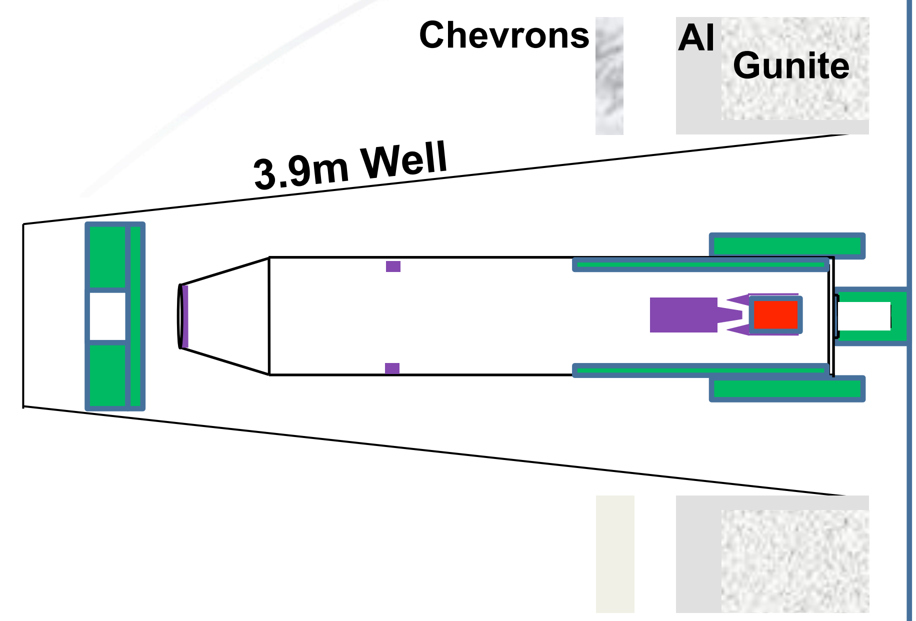
Direct GCD-3 vs GCD-1 comparison at 100 psia CO_2



GCD-3 has earlier precursor and cleaner return to baseline (faster response due to PMT110 vs 210)

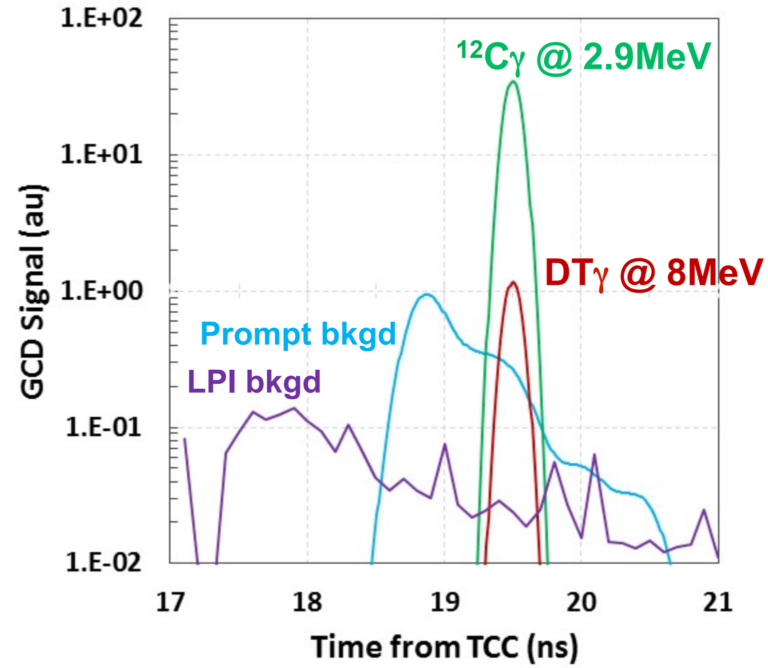
GCD-3 signals expected to be above background

Hevimet Tungsten Shielding



- **Existing Shielding** adequate for OMEGA
- ~200 lbs **Added Shielding** for 3.9m Well

MCNP Simulations*

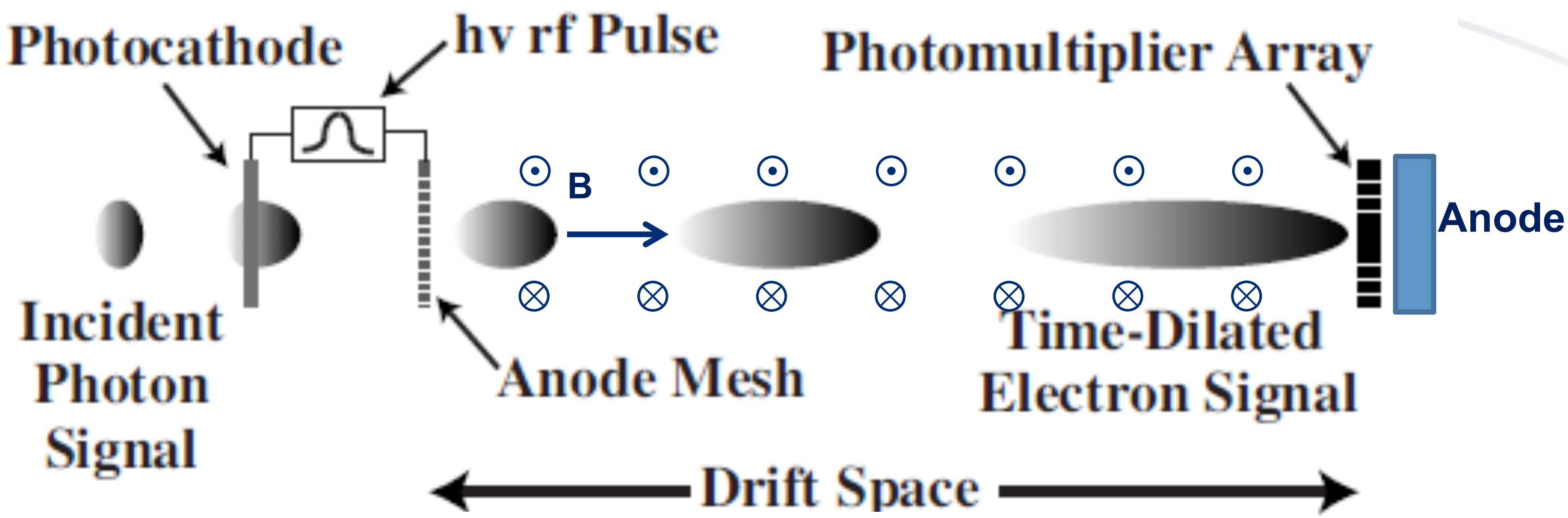


- LPI x-ray bkgd "easily" shielded
- Prompt γ bkgd may be significant (SNR~3) in "worst" case

*MCNP by H. Khater & S. Sitaraman

Super GCD to mitigate Prompt bkgds for Reaction History Measurements

Phase II - Pulse-Dilation PMT (FY16-FY17)



REVIEW OF SCIENTIFIC INSTRUMENTS **81**, 10E317 (2010)

Pulse-dilation enhanced gated optical imager with 5 ps resolution (invited)[a)]

T. Hilsabeck Th.Po.12

T. J. Hilsabeck,[1,b)] J. D. Hares,[2] J. D. Kilkenny,[1] P. M. Bell,[3] A. K. L. Dymoke-Bradshaw,[2] J. A. Koch,[3] P. M. Celliers,[3] D. K. Bradley,[3] T. McCarville,[3] M. Pivovaroff,[3] R. Soufli,[3] and R. Bionta[3]

Physics: Improved Reaction History (RH) at high yield (~10ps at >1e15)

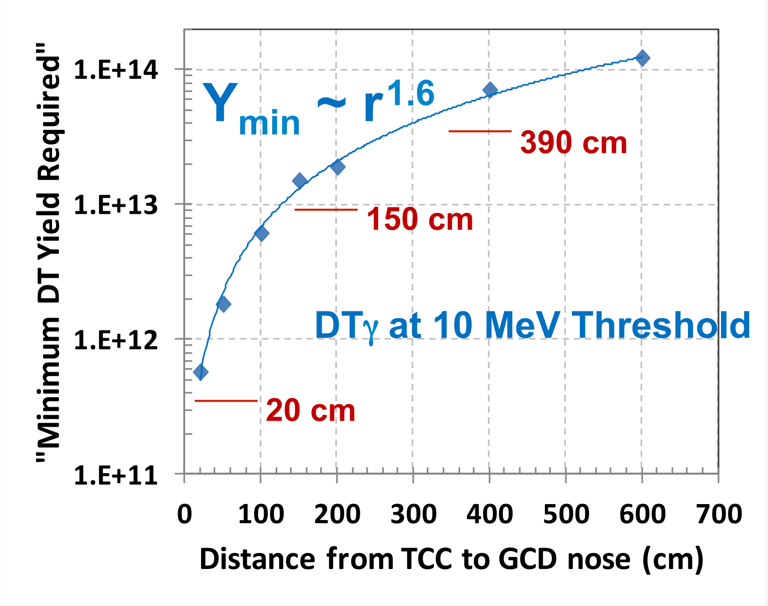
- Accurate GBT/GBW at **Burn Width <100 ps** fwhm
  - NIC BW~175ps, HiFoot BW~125ps, Ignition BW ~10 ps expected
  - LANL "Wetted Foam" low-CR targets expect BW <100 ps
- Non-Gaussian features (e.g., skewness, shock inflections, …)
  - Aid in exploration of Mix & Alpha Heating

Phase III - (FY16-FY18) Measure RH at low yield

- **Enhanced Shielding Super GCD** (100 lb GCD-3 → 275 lb Super GCD)
  - Improved gas cell temporal response for PD-PMT
- **Get detector in closer (DIM or TANDM)**

From (cm)	To (cm)	Sensitivity Increase
600	390	**~2x**
390	150	**~5x**
150	20	**~25x**

Yields as low as 5e11 DTn measurable



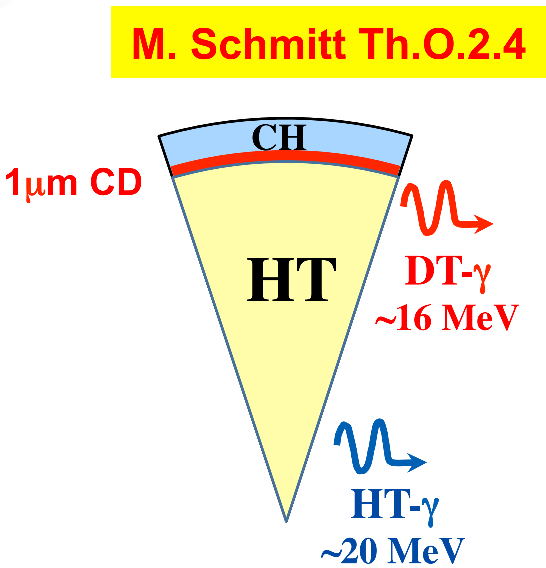
ACCEPT simulations, C.S. Young

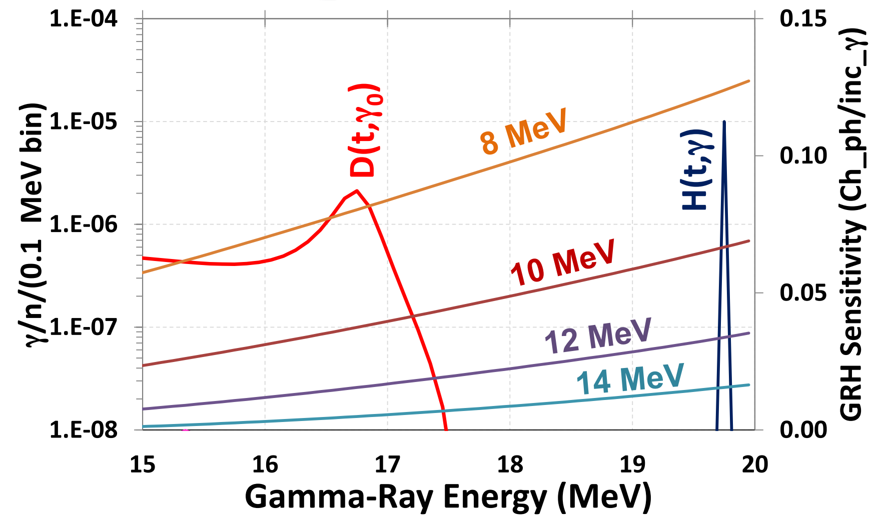
Physics:

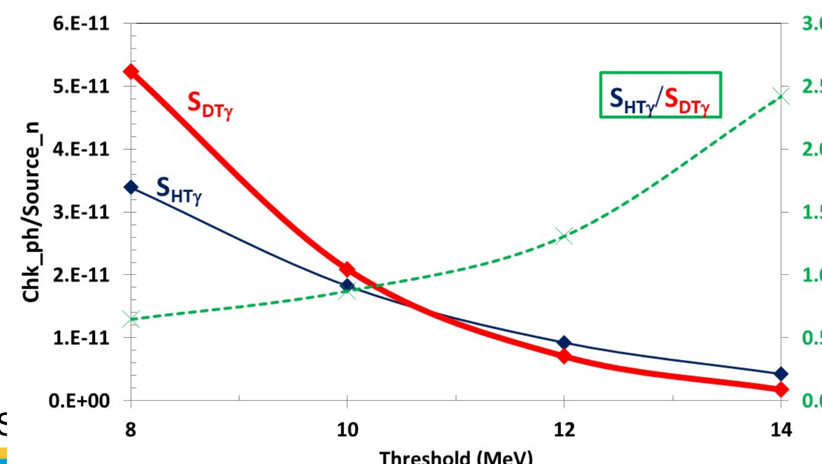
- Initial shock yield timing
- D^3He Symcap ($Y_{D3He\text{-}p} \approx 1e12$, BR=1.2e-4 γ/p)
- LANL's MARBLE Mix Campaign
- CD/HT Mixcap ($Y_{DT\text{-}n} \approx 1e12$, BR=4.2e-5 γ/n)

Time-resolved, Separated Reactant, Mix experiments will be made possible with HT gammas

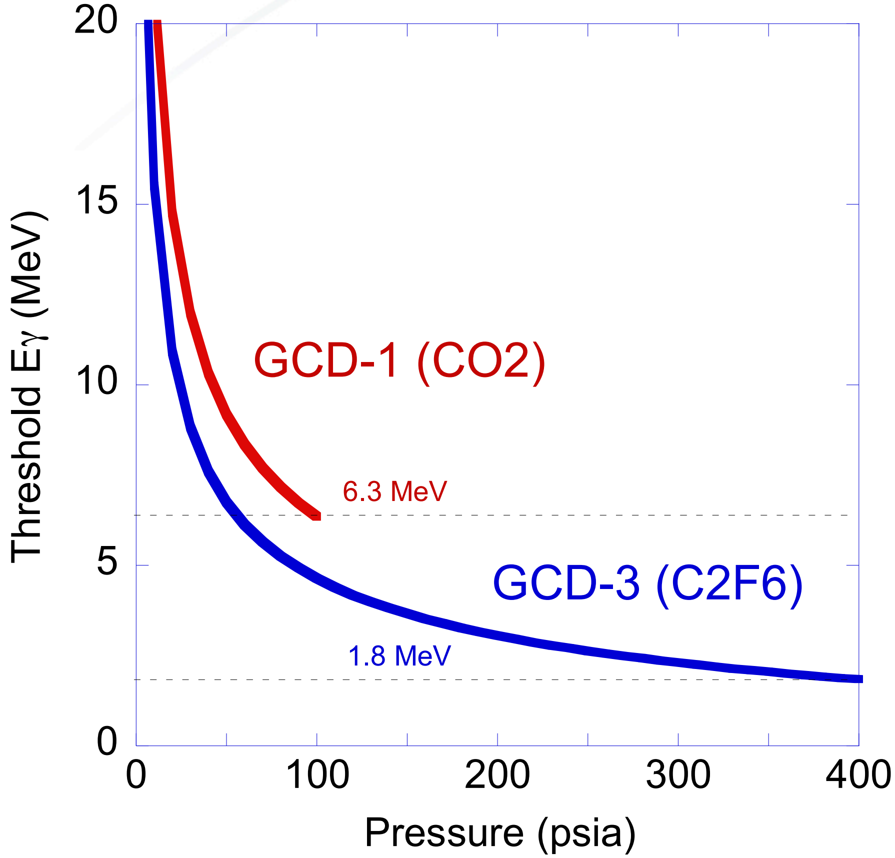
- FY16 shot days at OMEGA: THD & HKMix
- Requires high-sensitivity for low-yield → Super GCD in close







Low Energy Threshold (~ 2 MeV) enables new mission space



- **New gamma-ray detection**
  - **too dim for GRH**
  - **too low E for GCD-1**

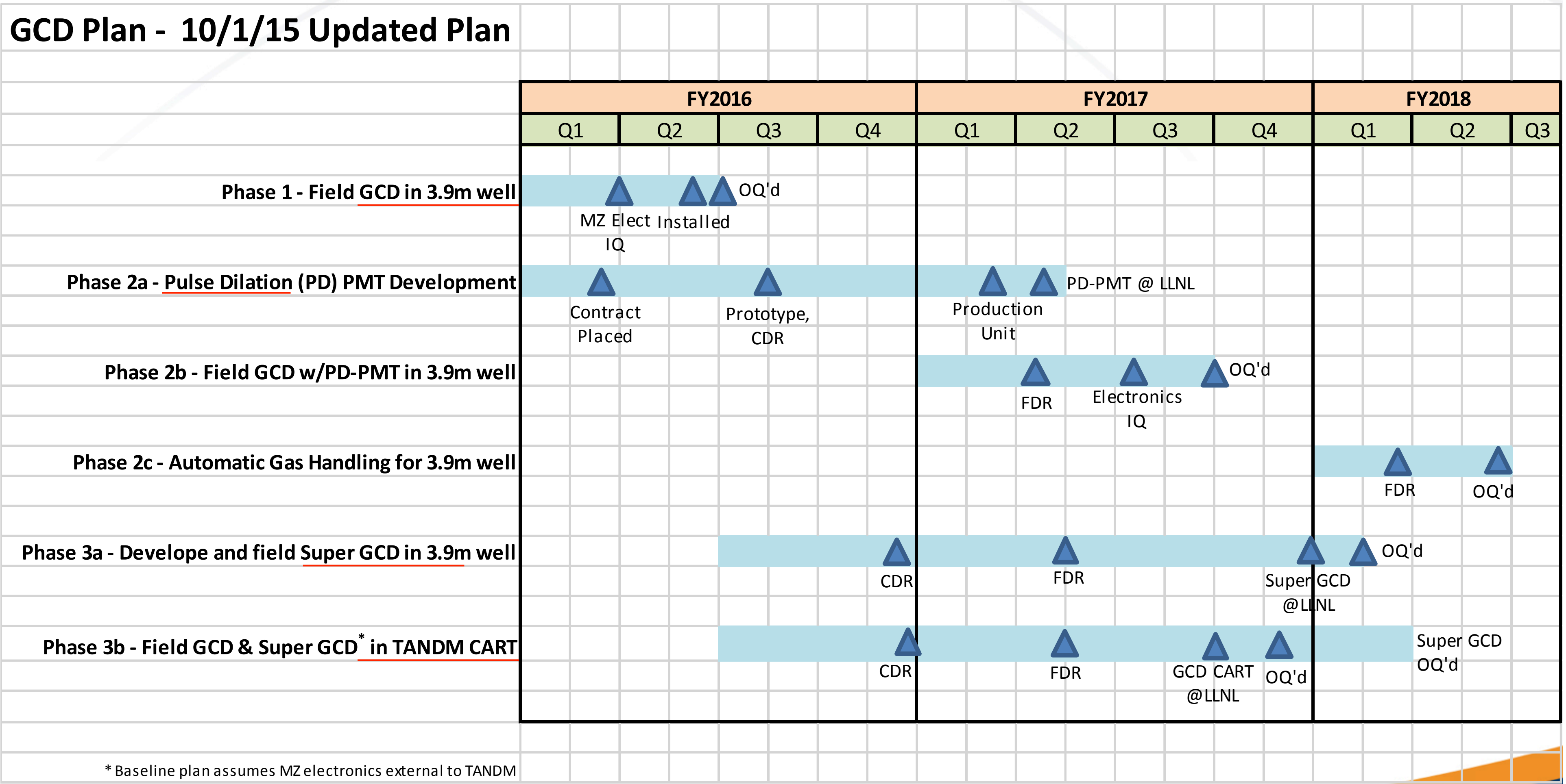
- $^{16}O(n,n'\gamma)$ at **6.1 MeV** (SiO_2 ρR)
- $^{13}C(d_{ko},n)^{14}N^*$ at **5.69 MeV**
- $^{9}Be(\alpha,n)^{12}C^*$ at **4.44 MeV**
- $^{9}Be(d_{ko},n)^{10}B^*$ **3.4 MeV**
- $^{10}B(d_{ko},n)^{11}C^*$ at **~7 MeV**

Mix

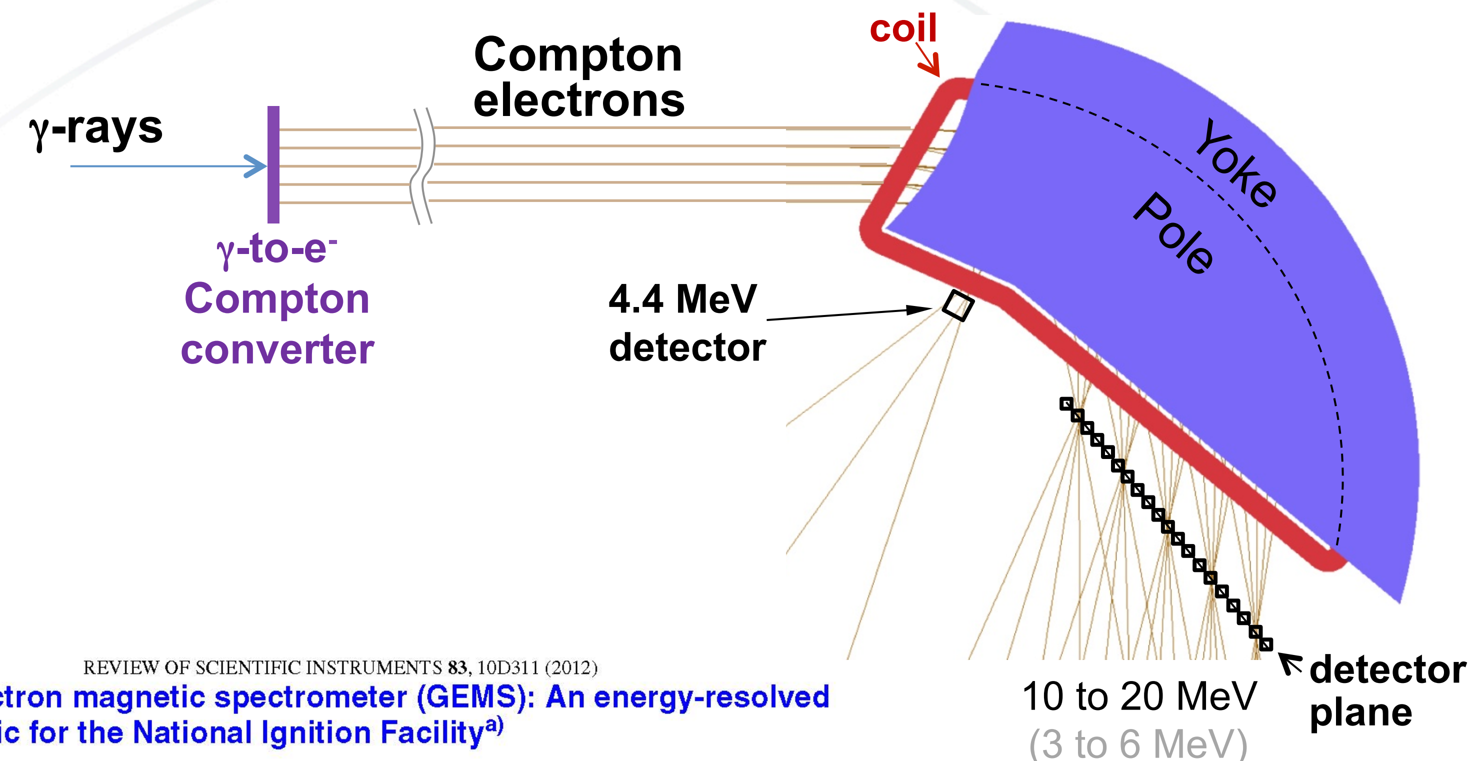
- HD-γ at **5.5 MeV** (MIT Zylstra PhD)
- T^3He-γ at 15.8 MeV

Discovery Science
Gatu-Johnson (MIT)

NIF GCD Gantt Chart



Gamma-to-Electron Magnetic Spectrometer (GEMS) to provide true energy resolution



REVIEW OF SCIENTIFIC INSTRUMENTS **83**, 10D311 (2012)

Gamma-to-electron magnetic spectrometer (GEMS): An energy-resolved γ-ray diagnostic for the National Ignition Facility[a)]

Y. Kim,[1,b)] H. W. Herrmann,[1] T. J. Hilsabeck,[2] K. Moy,[3] W. Stoeffl,[4] J. M. Mack,[1] C. S. Young,[1] W. Wu,[2] D. B. Barlow,[1] J. B. Schillig,[1] J. R. Sims, Jr.,[1] F. E. Lopez,[1] D. Mares,[1] J. A. Oertel,[1] and A. C. Hayes-Sterbenz[1]

REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 11E122 (2014)

Conceptual design of the gamma-to-electron magnetic spectrometer for the National Ignition Facility[a)]

Y. Kim,[1,b)] H. W. Herrmann,[1] H. J. Jorgenson,[1] D. B. Barlow,[1] C. S. Young,[1] W. Stoeffl,[2] D. Casey,[2] T. Clancy,[2] F. E. Lopez,[1] J. A. Oertel,[1] T. Hilsabeck,[3] K. Moy,[4] and S. H. Batha[1]

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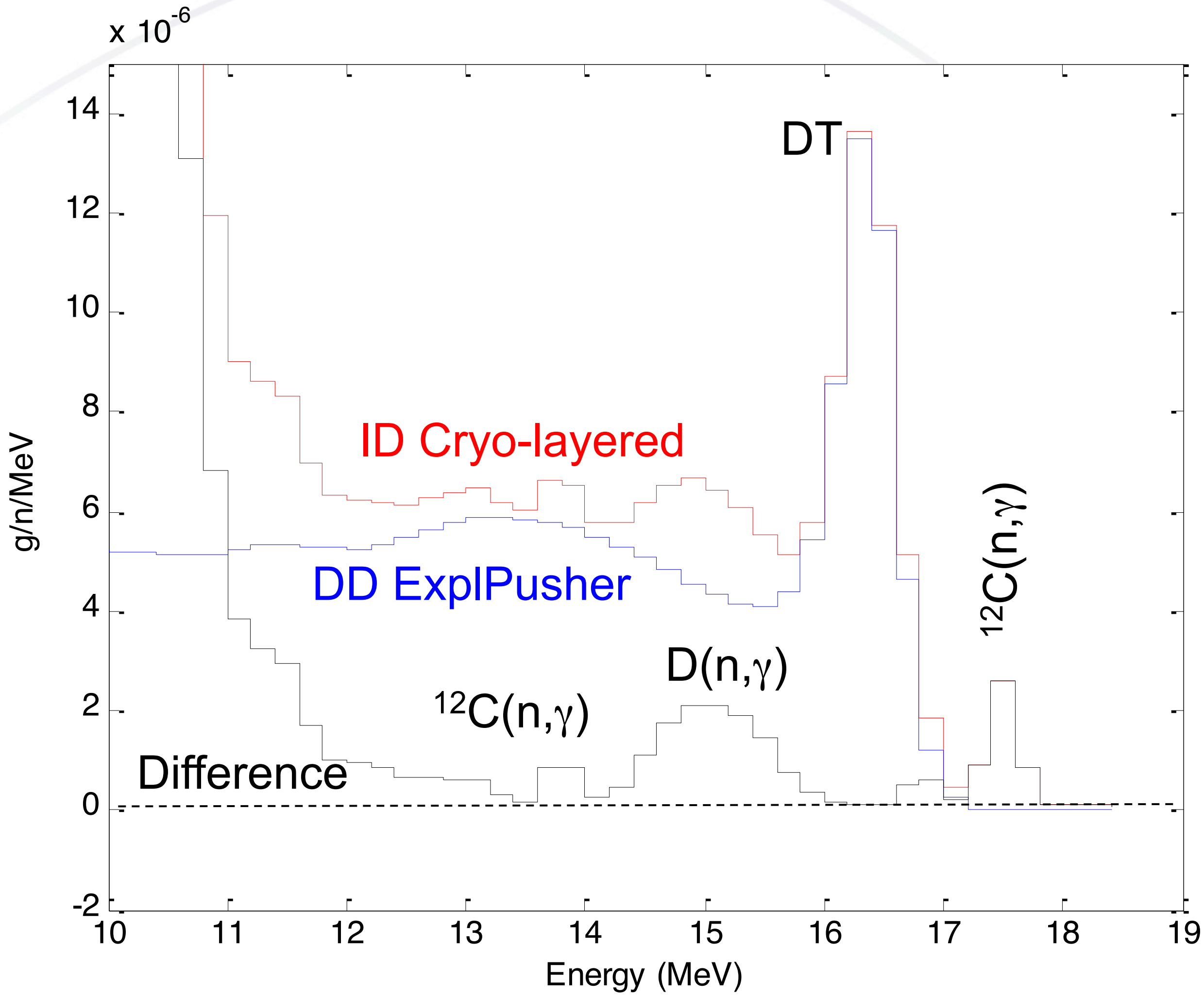
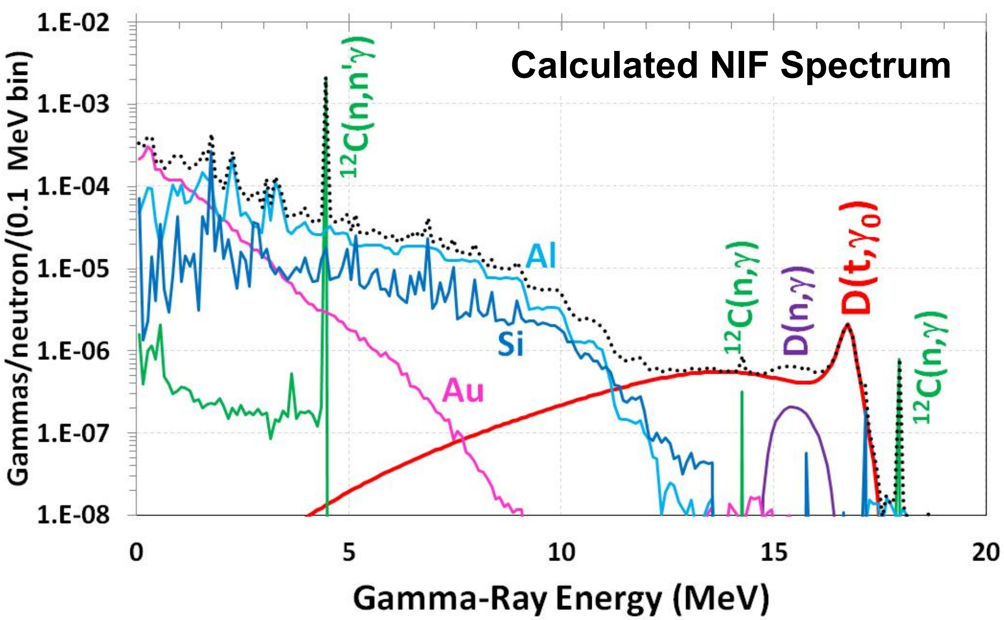
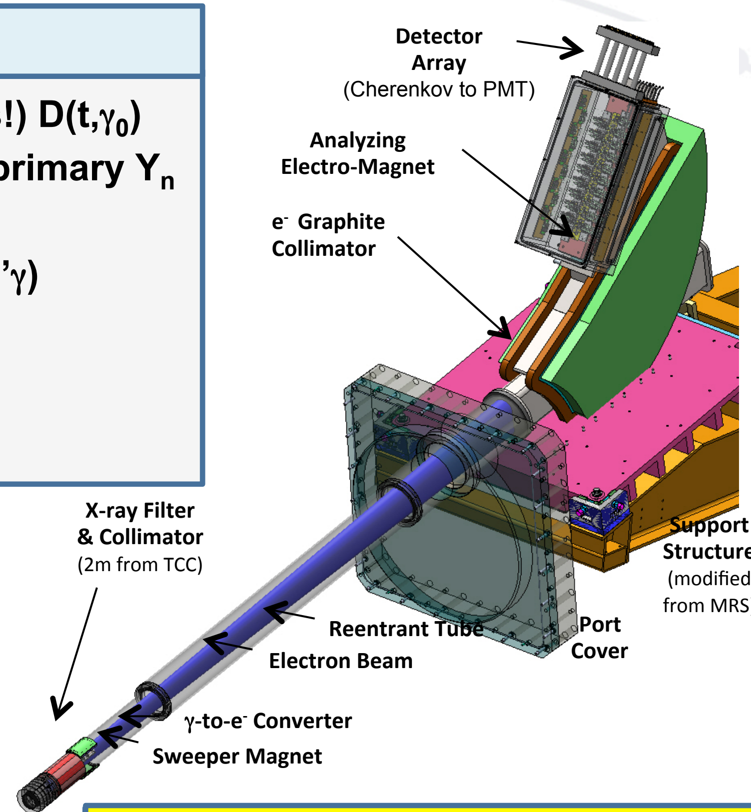


Gamma Spectroscopy will be an enabling technology for NIF

GEMS (Gamma-to-Electron Magnetic Spectrometer)

- Total Yield (no Total Yield measurement currently exists!) $D(t,\gamma_0)$
- Total Down Scatter Fraction (TDSF) when combined w/ primary Y_n
- 4π Global Fuel ρR (Fuel ρR currently line-of-sight) $D(n,\gamma)$
- Ablator ρR (reduced uncertainty relative to GRH) $^{12}C(n,n'\gamma)$
- Mix studies (e.g., $^{9}Be(\alpha,n\gamma)$, $^{13}C(d,n\gamma)$, $^{11}B(d,n\gamma)$)
- Neutron Interactions on materials (i.e., pucks)
- Astrophysical studies (e.g., s & r-processes)





NIF CDR held in July 2013

- Energy Resolution: $\Delta E/E \leq 5\%$
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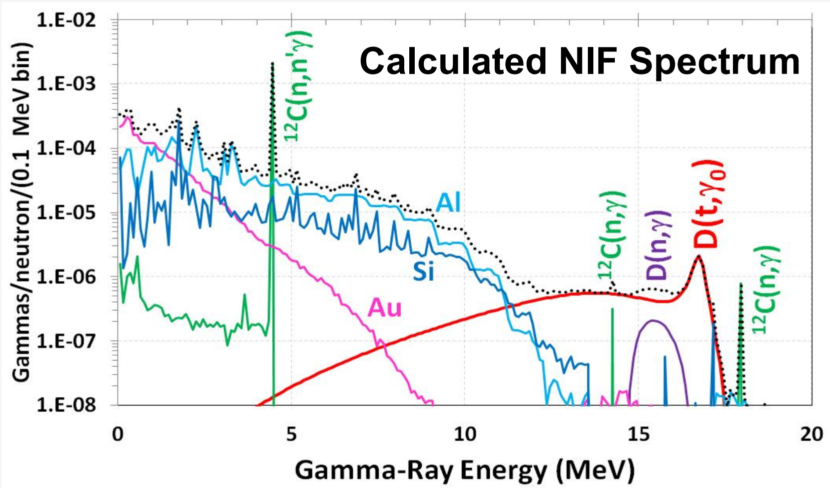
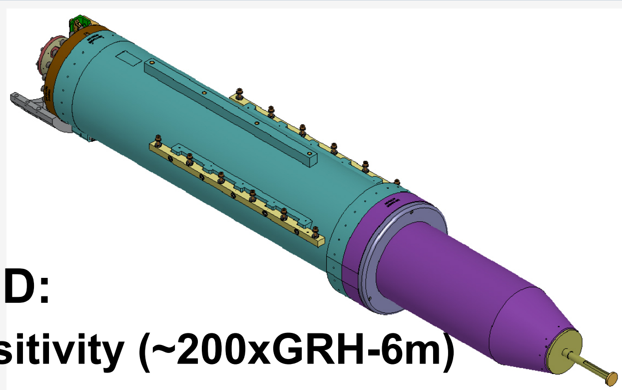


Enhanced Gas Cherenkov Detectors for Reaction and ρR_{Abl} Histories



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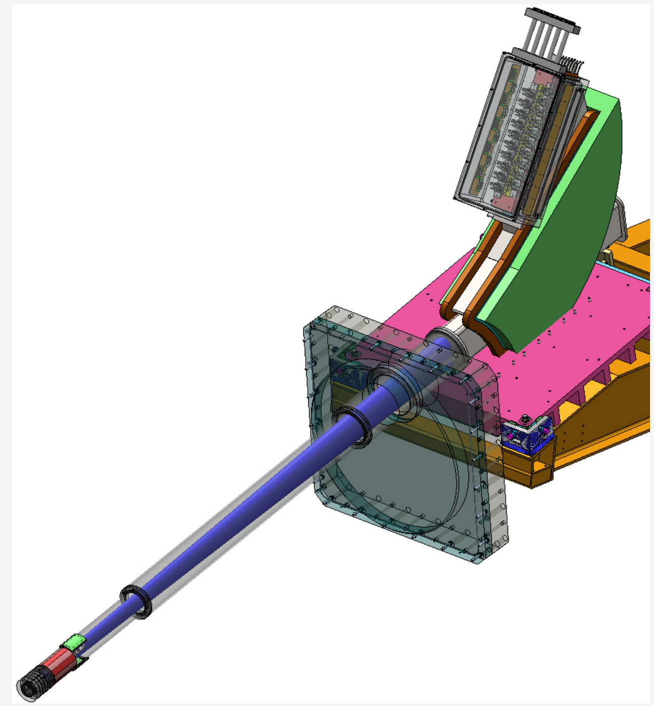

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Backups

Key Capability Improvements enable "Super" GCD to meet its goals

- Improved temporal resolution
  - ~**60 ps** w/ Photodiode (but unity gain)
  - ~**10 ps** with Time Dilation-PMT (further development required)
    - ➢ Current GRH/GCDs limited by MCP PMT to **~100 ps**
- Increased sensitivity (at 20 cm from TCC):
  - >**20x** sensitivity of **OMEGA GRH-2m** at fixed threshold achieved
  - >**200x** sensitivity of **NIF GRH-6m** at fixed threshold
- Low threshold (additional sensitivity and new spectral window)
  - As low as **1.8 MeV** with 400 psia C_2F_6
    - ➢ GCD-1 limited to **≥6.3 MeV**
    - ➢ GRH limited to **≥2.9 MeV**

Super GCD is at a High Technical Readiness for NIF

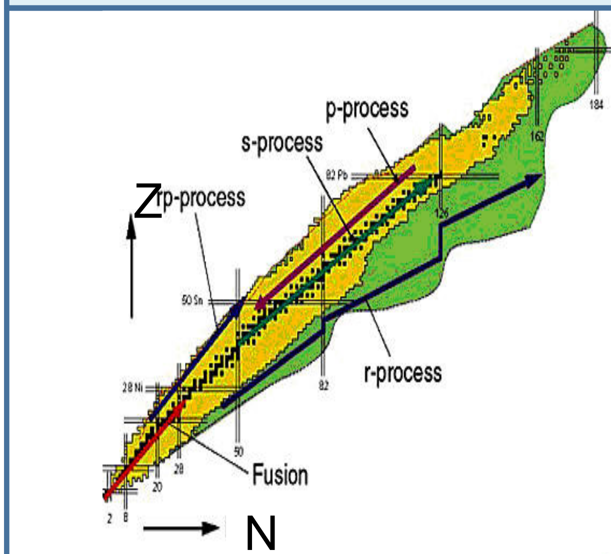
Super GCD (Gas Cherenkov Detector) will enable enhanced Gamma Ray Detection at NIF with:

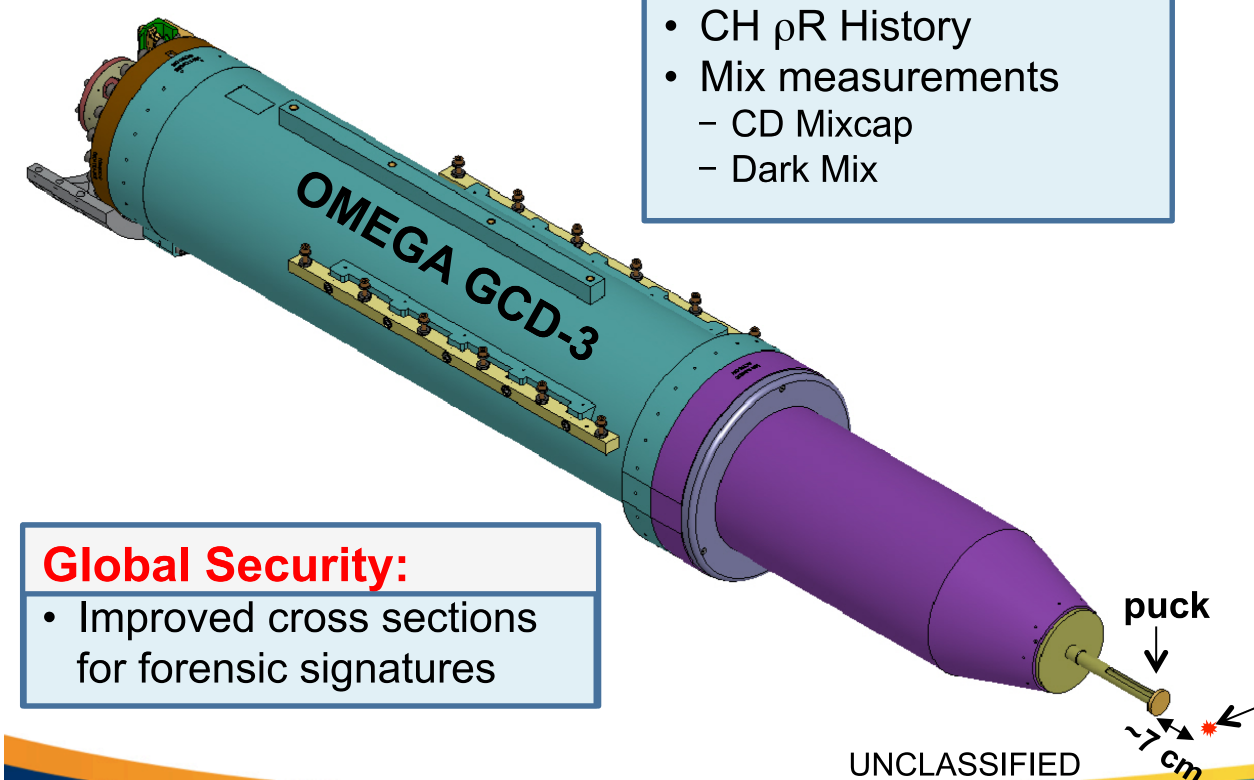
1) High Sensitivity (~200xGRH-6m)
2) High Temporal Resolution (~10 ps for DTγ vs 100 ps for GRH-6m)
3) Low Energy Threshold (1.8 MeV vs 2.9 MeV for GRH-6m)

Missions:

TN Burn:
- Reaction History
- CH ρR History
- Mix measurements
  - CD Mixcap
  - Dark Mix

Discovery Science:
- Astrophysical s-process
- Big Bang Nucleosynthesis
- Stellar pp Fusion Chain

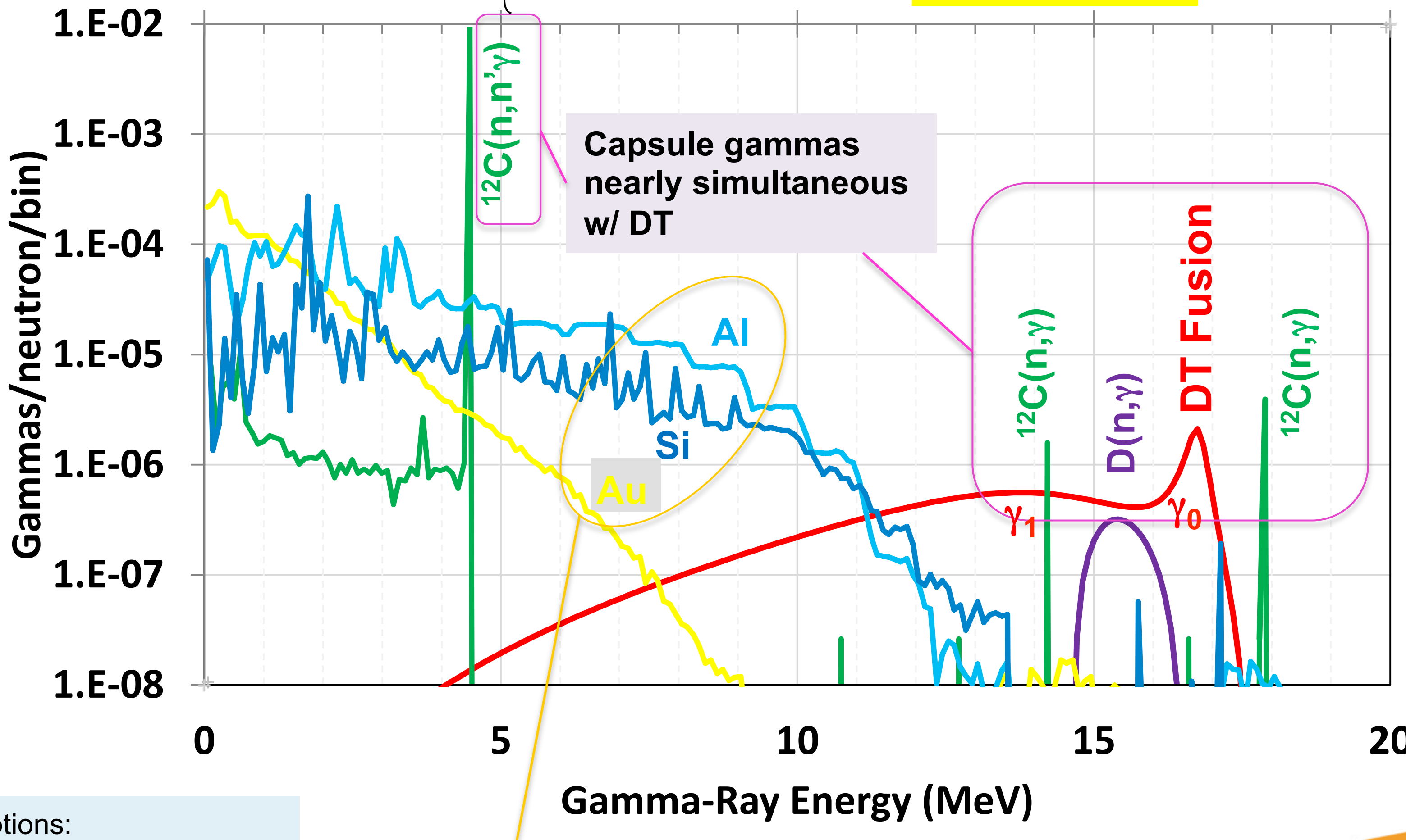




Global Security:
- Improved cross sections for forensic signatures

The Prompt γ-Ray Energy Spectrum from Indirect-Drive, Cryo-Layered Implosions is complicated and never directly measured!

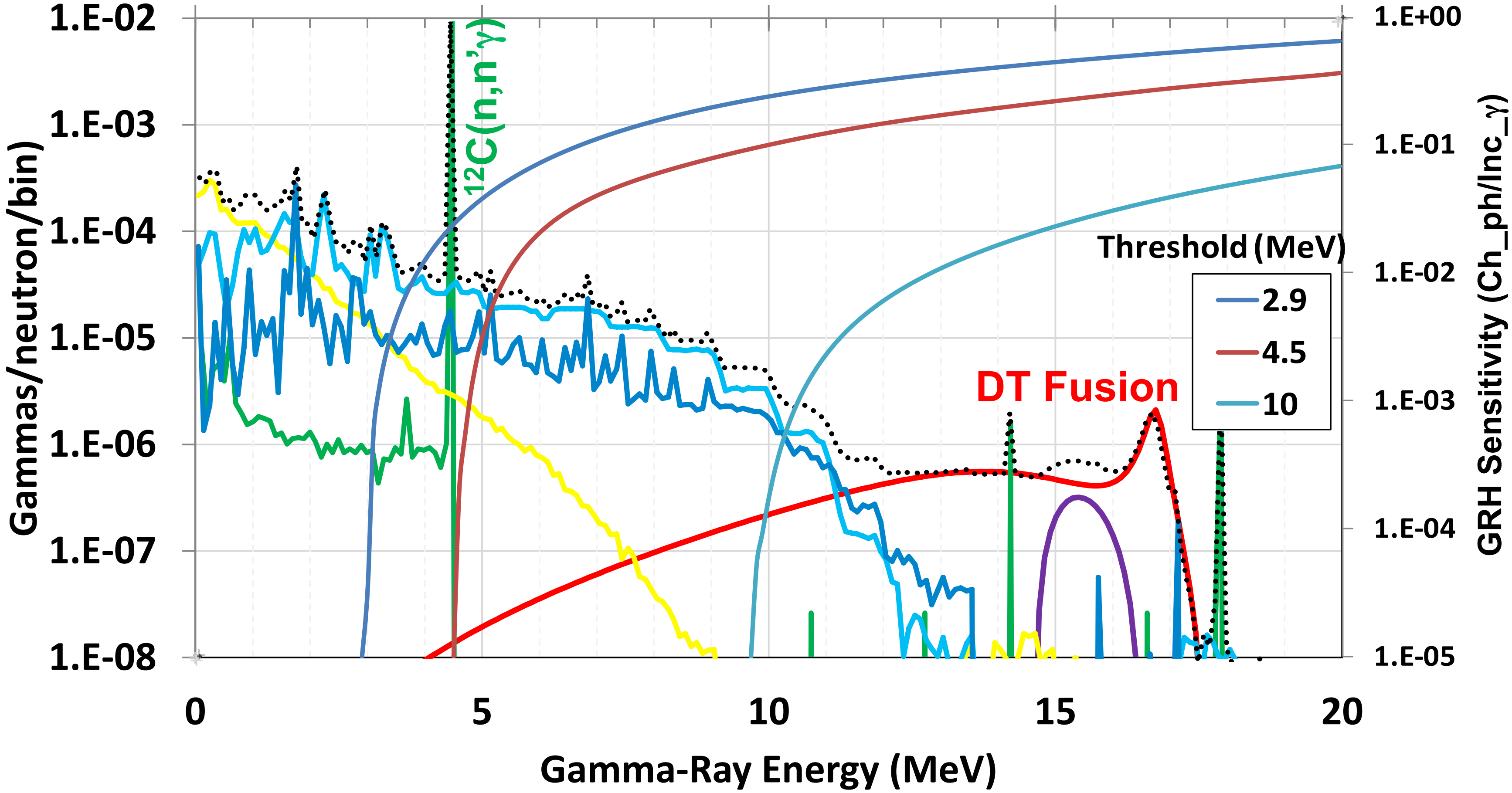
$$D + T \rightarrow {}^5He^* \begin{cases} \xrightarrow{\sim 1} n\,(14.1\ MeV) + \alpha\,(3.5\ MeV) \\ \xrightarrow{\sim 4e-5} {}^5He + \gamma\,(16.75 MeV) \rightarrow n + \alpha \end{cases}$$



Assumptions:

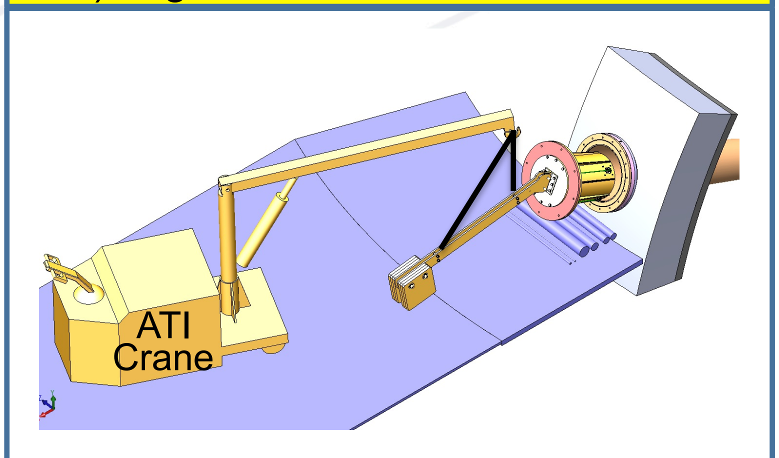
- BR(γ/n) = 4.2e-5 γ/n
- γ_1/γ_0 = 2.3
- ρR_{12C} = 0.5 g/cm^2
- ρR_{DT} = 1.5 g/cm^2

Thresholded Cherenkov detectors provide high temporal bandwidth at cost of spectral resolution

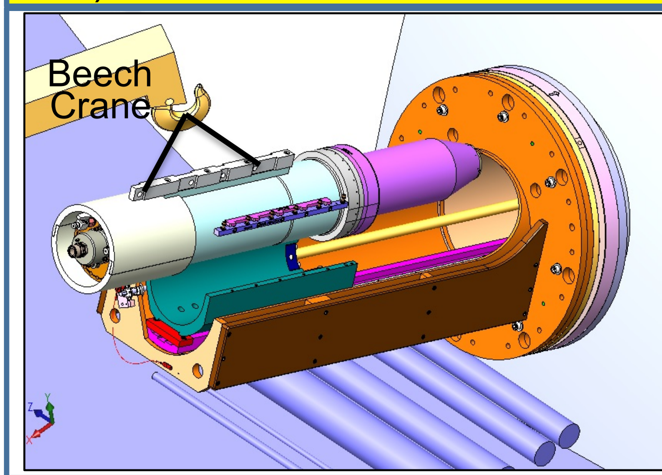


Three Rigging Operations (2 of which are one-time only)

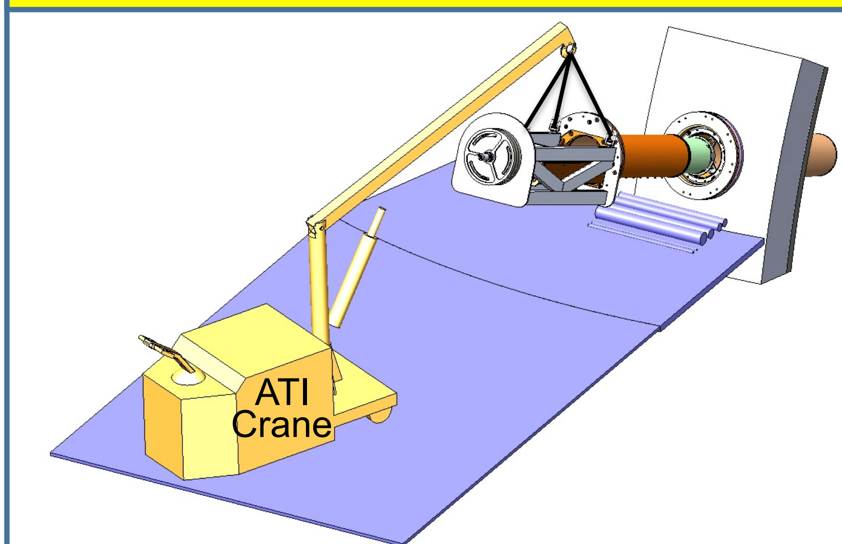
1) Alignment Fixture



3) Gas Cell

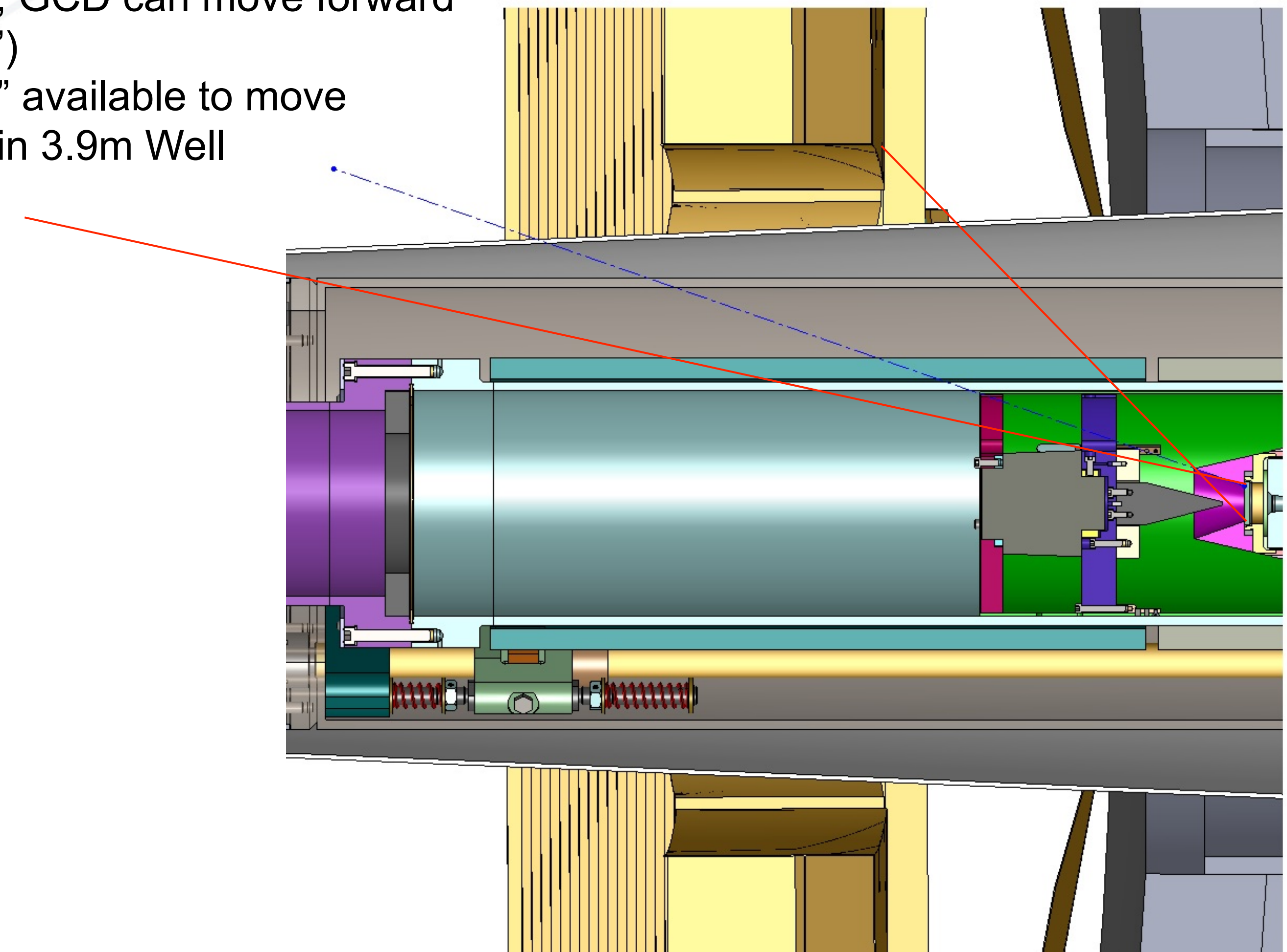


2) Carrier Support Assembly (CSA)



GCD3 photocathode is exposed to 1st Wall scattering

- Collimator face at 3.967m
  - Only have ~60mm (~2.4”) available to move forward w/in 3.9m well
  - In addition, GCD can move forward ~4cm (1.6”)
  - Total of ~4” available to move forward w/in 3.9m Well



Would need to move GCD3 forward ~½ ft to shield 1st Wall with "bat ears" (another few inches to take advantage of external W cylinder)